HISTORICAL REVIEW OF CARNOTITE MINING IN SOUTHWESTERN COLORADO

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INTRODUCTION AND GEOLOGICAL SETTING

The carnotite deposits of southwestern Colorado and southeastern Utah have been important sources of radium, vanadium, and uranium since the early 1900's. Due to falling prices of both uranium and vanadium the mines in the region have been closed since 1991. The ore deposits occur in the Salt Wash Member of the Morrison Formation of Late Jurassic age (150 million years ago). This geologic unit occurs over a wide area of the Colorado Plateau of western Colorado, eastern Utah, northwestern New Mexico and northeastern Arizona.

The most productive carnotite mines in southwestern Colorado were located on north and south rims of Paradox Valley in western

Montrose County, Colorado. In this area, the Salt Wash Member consists mainly of sandstone which is whitish-gray to light buff in color. Interbedded with the sandstone beds are thin beds of reddish-brown to greenish-gray shale and mudstone, and a few thin beds of gray limestone. Most of the sandstone occurs in single beds or lenses that may reach a thickness of 60 feet. Features within the sandstones, such as ripple marks, current lineations, rill marks, and cut and fill structures indicate that the Salt Wash was deposited in a fluvial environment. Carbonaceous fossil plant material is common in the host sandstones. The Salt Wash is 280-350 feet thick in the Paradox Valley area. In this area, sandstone beds within the Salt Wash form three prominent cliffs. The ore deposits occur in the upper sandstone beds, commonly called "the third rim" by the miners. In the early 1950's, an elongated area in southwestern Colorado containing larger, higher grade, and more continuous deposits was named the Uravan Mineral Belt (Figure 1).

The orebodies consists mostly of sandstone selectively impregnated and in part replaced by uranium and vanadium minerals; but rich concentrations of carnotite and the micaceous vanadium clay minerals are also associated with thin mudstone partings, beds of mudstone pebbles, and carbonized fossil plant material. Many fossil logs replaced by nearly pure carnotite have been found. In general the ore minerals were deposited in irregular layers that roughly followed the sandstone beds. In most deposits the highest-grade concentrations of ore minerals occur in sharply bounded, elongate concretionary structures, called "rolls" by the miners.

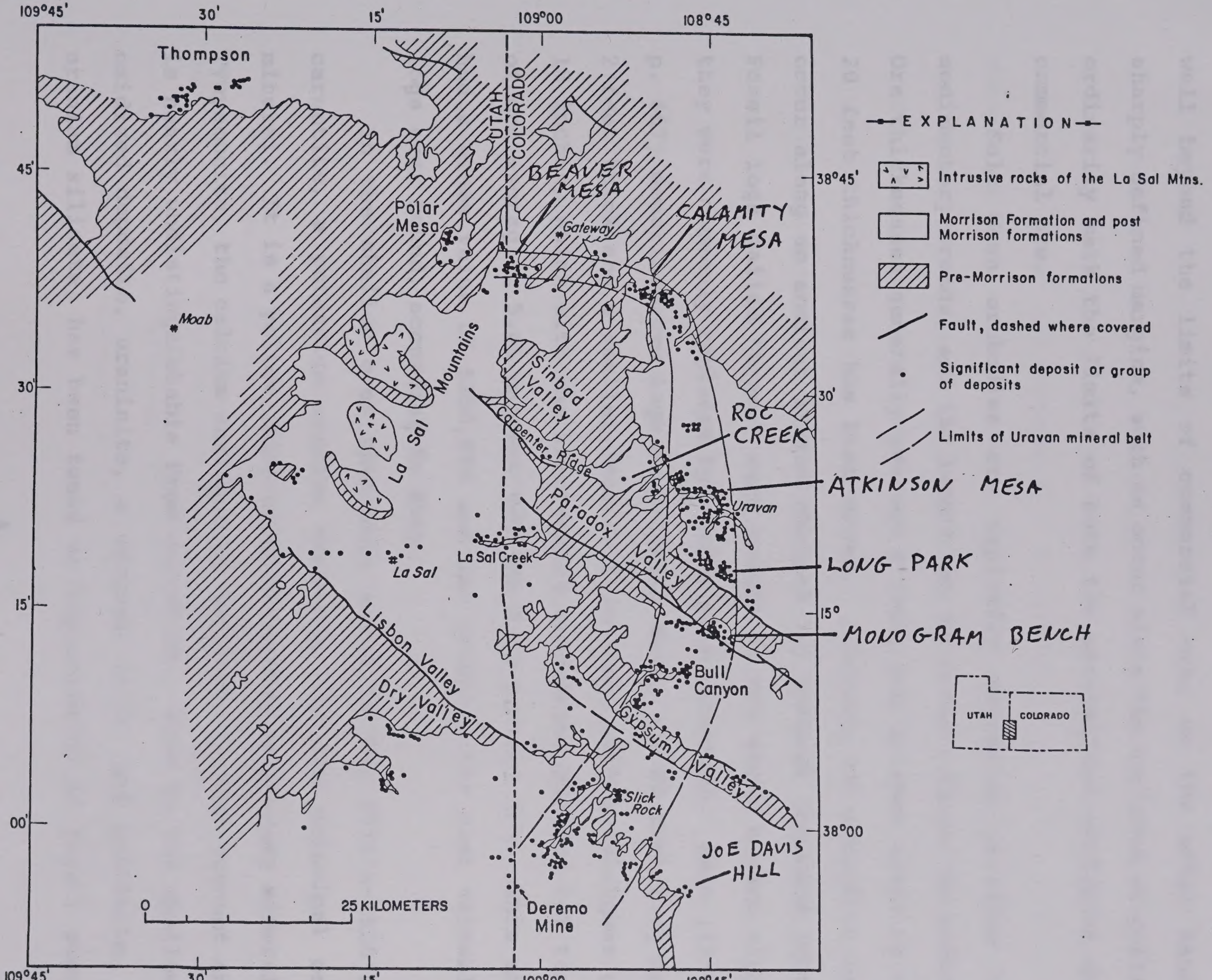

Figure 1 - Index map of southwestern Colorado and southeastern Utah showing the location of uranium-vanadium deposits in the

Margins of orebodies may be vaguely or sharply defined. Vaguely defined margins may have mineralized sandstone extending well beyond the limits of commercial ore; on the other hand, sharply defined margins, such as occur along the surfaces of rolls, ordinarily mark the limits of both the mineralized sandstone and commercial ore.

Salt Wash orebodies are typically elongated parallel to sedimentary trends, and the length may be several times the width. Ore thicknesses generally average 4 feet, but in some areas up to 20 feet thicknesses has been mined. Clusters of orebodies may occur along an ancient stream channel for several thousand feet. Fossil logs called "trees" were sought by the early miners since they were commonly replaced by nearly pure carnotite. Hess (1933, p. 467) described two logs on Calamity Mesa; one 80 feet long and 2 feet thick and a smaller one, 30 feet away, with a thickness of 18 inches, which with the intervening sandstone, yielded 180 tons of ore averaging 5.65 percent U_3O_8 and 8.00 percent V_2O_5. This ore had a gross value of $350,000 and was probably the most valuable logs ever found, according to Hess.

In the shallow ores that were mined in the 1910's-1920's, carnotite, a potassium uranium vanadate, was the principal ore mineral. It is a yellow, fine-grained, earthy or powdery mineral. Tyuyamunite, the calcium analogue of carnotite is also present and is nearly undistinguishable from carnotite. Even in the shallow, oxidized deposits, uraninite, a uranium oxide, and coffinite, a uranium silicate, has been found as replacements of fossil plant

material. Uraninite is found replacing the cell walls of fossil wood, especially in fossil logs, and coffinite is commonly found filling cell cavities in plant material.

Vanadium clays, consisting largely of chlorite and/or hydromica, are the main vanadium minerals in both oxidized and unoxidized ores and deposits. Montroseite is present in the unoxidized ores and corvusite is common in the partly oxidized deposits. The oxidation of vanadium forms a series of vanadate minerals which include: tyuyamunite, metatyuyamunite, carnotite, hewettite, metahewettite, pascoite, rauvite, rossite, metarossite, fervanite, and hummerite. Generally the amount of vanadium exceeds the uranium in ratios ranging from 3:1 to 10:1. Ores mined in the area have averaged 5:1. Within the Uravan mineral belt, the vanadium increases southward from Gateway (3:1) to Slick Rock (8:1). These ratios are based on uranium production since 1947 and include both oxidized and unoxidized ores. With a few local exceptions, both oxidized and unoxidized ores are in radioactive equilibrium.

EARLY HISTORY

The history of the mining of carnotite deposits in southwestern Colorado and southeastern Utah reflects the importance of three metals - radium, vanadium, and uranium. Much of the historical material in this summary is taken from a report by Webber (1947).

The existence of a yellow substance in the Paradox Valley rimrock of Montrose County, Colorado was known to the settlers prior to 1880. It is assumed that the Ute and Navajo Indians used this yellow powder as a pigment before the white settlers came to the region.

In 1881, a prospector named Tom Talbert sent some yellow material from the Roc Creek area of Montrose County to an assayer in Leadville to determine its content. This and other early attempts to detect the elements present in the yellow material were unsuccessful. About 1896 the claims on Roc Creek were relocated by Tom Dullan. Gordon Kimball and associates of Ouray, Colorado, leased the property in 1898 and sent some of the yellow material to Charles Poulot in Denver who found it contained uranium in sufficient quantity to make it valuable. During June 1898, Gordon Kimball shipped 10 tons of ore from the Roc Creek property to Denver. This shipment averaged 21.5 percent uranium oxide (U_3O_8) and over 15 percent vanadium oxide (V_2O_5) for which Kimball was paid $2,600 (Kimball, 1904). The high vanadium content resulted in a penalty when the shipment was re-sampled in France. In 1899 Charles Poulot and another Frenchman Charles Voilleque sent mineral specimens to France where C. Friedel and E. Cumenge established the approximate composition of this mineral and named it carnotite, after the French mining engineer and chemist Adolphe Carnot.

Soon after the first shipment of carnotite it became known that the yellow mineral was marketable, and many claims were

staked. Most of the claims were located along Roc Creek, along La Sal Creek, and in adjacent areas.

In 1900, Poulot and Voilleque conducted experimental work on extracting vanadium and uranium oxides from carnotite ores at the camp of the Cashin copper mine on La Sal Creek. The ores used in these experiments came from mines on Roc Creek, on La Sal Creek, and on the San Miguel River (Figure 1). As a result of these studies, a company formed by Poulot, Voilleque, and James McBride built an experimental mill at the mouth of Summit Creek in the Slick Rock area (Figure 1). About 15,000 pounds of uranium-vanadium concentrates were produced at this plant before operations were transferred to the Western Refining Company in 1903 and to the Dolores Refining Company in 1904 (Lundquist and Lake, 1955). This activity created much interest in carnotite areas, and widespread claim staking occurred throughout the area between 1902 and 1905. According to Fischer (1968, P. 738), between 1898 and 1909 total production from the region was 9,000 tons of high-grade ore. With the exception of ore from the vicinity of the Summit Creek plant, all ore mined before 1906 was shipped either to the eastern part of the United States for vanadium recovery or to Europe for the recovery of radium.

RADIUM

The discovery of radium by Marie and Pierre Curie in 1898 led to the realization that all uranium ores contained this new

element. Uses of radium by the medical community were developed, and hence an incentive to mine the carnotite ores were perfected. Radium compounds were found to glow in dark and uses of radium paint were invented.

Shortly before 1910, metallurgical processes for relatively large-scale recoveries of radium from carnotite ores were perfected. About one gram of radium is present in every 200-300 tons of ore containing 2.00 percent U_3O_8. The improved processes resulted in greatly increased demands for carnotite and in accelerated prospecting in the area. By 1911 there was a rush of claim staking which affected the entire region. During the mid-1910's many claims were patented, especially in the Paradox Valley area.

Shortly after 1910, the carnotite deposits in southwestern Colorado and southeastern Utah became one of the principal world sources or radium. For about 10 years, (1913-1922), these deposits were mined for radium and yielded some byproducts of uranium and vanadium. The Standard Chemical Company of Pittsburgh, Pennsylvania would become the largest producer of radium ore in the area the company was founded by the Flannery brothers, Joseph, James, and John, in about 1910. The Flannery's had previously formed the American Vanadium Co. to produce vanadium from deposits in Peru.

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1924). High-grade ore, greater than 2.00 percent U_3O_8, was shipped, via the railroad at Placerville, Colorado, to Standard's plant at Canonsburg, Pennsylvania. During the years 1912-1914, Standard Chemical operated a dry-process concentrator on the banks of the San Miguel River, where Uravan, Colorado is now located. This process used compressed air to separate the sand grains from the fine fraction containing the carnotite, clay minerals, etc. In 1914 the milling process was changed to a wet concentration, and the plant was enlarged (Bruyn, 1955, p.58). The concentrator, known as the Joe Junior mill, could treat ores as low as 1.25 percent U_3O_8, but the average grade of ore treated ran 1.50 percent U_3O_8 or better. The concentrates produced at the mill averaged between 6.00 and 8.00 percent U_3O_8. The mill recovery averaged from 65 to 85 percent (Webber, 1947, p. 190). The concentrates from the Joe Junior mill were shipped to the plant at Canonsburg via the railhead at Placerville. Standard Chemical had mines in Montrose and San Miguel Counties, as well as in southeastern Utah. Hess (1921) noted that in 1918 Standard had 375 claims in the area of Paradox Valley. Up to 1921, Standard Chemical Co. had produced about 38,000 tons of ore that averaged 1.50 percent U_3O_8 and 2.75 percent V_2O_5 (Bruyn, 1955 p.59).

During the years 1913 through 1921, Standard Chemical produced 74 grams of radium or about 47 percent of the total domestic radium production (Landa, 1987, p.25). The American Rare Metals Company purchased the Summit Creek plant at Slick Rock and recovered some

uranium and vanadium as well as radium during 1912 and 1913 (Lake and Lunquist, 1955).

The National Radium Institute was formed in October 1913. It was a cooperative effort between the U.S. Bureau of Mines and private industry to develop radium extraction techniques so that radium could be used in medical therapy, and to disseminate such technical information to producers and users of radium. Dr. Howard A. Kelly of John Hopkins University, a cancer specialist, was named president of the Institute (Bruyn, 1955, p. 45).

Sixteen claims of the Crucible Steel Mining and Milling Co. in the Long Park area were leased for an ore supply. A mining camp and dry-process concentrator were established in the area of the claims. A laboratory and extraction plant were built in Denver, Colorado. Concentrates were shipped to Denver via the railhead at Placerville. The Institute's mining and milling operations in Long Park have been described in detail by Kithel and Davis (1917).

The National Radium Institute closed in 1916 after producing 8.5 grams of radium from 1,600 tons of ore (Bruyn 1955, p. 46). The Institute had fulfilled its mission. It aided both industry and medicine.

After the Long Park concentrator of the Institute closed, it was purchased by the Pittsburg Radium Company and moved a few miles to the northwest to Saucer Basin. However, after treating about 2,000 tons of ore, the dry process did not prove successful, and the mill was dismantled (Webber, 1947, p. 190).

Dr. W. A. Schlesinger started a radium refining laboratory at Princeton University in 1914. The next year Dr. Schlesinger and associates formed Schlesinger Radium Co., and built a radium reduction plant in Denver, Colorado. Carnotite claims were acquired on Roc Creek in Montrose County, Colorado. In 1917, the company became known as the Radium Company of Colorado and had 40 claims in the Long Park and Gypsum Valley areas of Montrose County (Hess, 1921).

During the late 1910's and early 1920's Radium Company of Colorado produced between 1,000 and 1,200 tons of carnotite ore per year. Since the company's extraction plant was located in Denver, a minimum shipping grade of 2.00 percent U_3O_8 had to be maintained.

The Carnotite Reduction Co. of Chicago, Illinois was a small carnotite producer with claims in the Gateway, Colorado and Dry Valley, Utah areas (Figure 1). In 1920 the claims of this defunct company were purchased by the Tungsten Products Co. of Boulder, Colorado (Landa, 1987, p. 20). In 1921, Tungsten Products merged with the Radium Company of Colorado. Radium Company of Colorado was the second largest producer of radium in the United States behind Standard Chemical Co. (Bruyn, 1955). Between 1915 and 1921 the firm produced about 45 grams of radium.

During 1921, Radium Company of Colorado closed its Long Park mines, and began mining on Calamity Mesa and in the Dry Valley, Utah area (Figure 1). Jake Lewis and associates leased the Calamity Mesa claims in 1924 and sold some high grade ore to U.S. Radium Corp., in 1924 and 1925. Ore produced on Calamity Mesa was

shipped to Denver and or New Jersey via the railhead at Whitewater, Colorado. Radium Company of Colorado went out of business and the Gateway claims were sold to the Atlas Corp. in 1925 (Webber, 1947, p.191).

Radium Luminous Material Corp. (RLM) was founded in 1914 in Newark, New Jersey. Sabin A. von Sochocky, the founder, had developed luminous paints for use on clock and watch dials. RLM began acquiring claims in Long Park in 1914 and mining commenced in 1915 (Innes, 1919). By 1919, RLM controlled 5 patented and 65 unpatented claims in Long Park, 8 claims in the La Sal Creek area, 13 claims in Silvey's Pocket and 4 claims in the Roc Creek area, all in Montrose County. An additional 9 claims were held in the Slick Rock area of San Miguel County (RLM, 1920). In May 1921, Radium Luminous Material Corp. became U.S. Radium Corp. The firm continued to operate in Montrose County until 1923, after which they purchased ore from independent miners. U.S. Radium purchased ore that was mined on Calamity Mesa by Jake W. Lewis in 1924 and 1925 (Hess 1927,1928). All ore mined and or purchased by RLM/U.S. Radium was shipped to its plant in East Orange, New Jersey. Up to 1921 RLM's had produced 30 grams of radium (Landa, 1987), the third largest domestic producer.

W. L. Cummings Chemical Co. mined carnotite ore in the Bull Canyon area of Montrose County, Colorado in the mid 1910's. In 1918, Hess (1921) noted the company had 35 claims in the Paradox Valley area, but had been inactive for three years. The company produced some radium salts in 1921 (Tyler, 1930).

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Prospectors used their eyes to locate mineralized outcrops. They learned to look for the yellow-colored exposures of carnotite in the gray sandstone beds above the salmon-colored "slick-rim". This location had been learned from the pre-1900 discoveries in various parts of the region. Paradox Valley, with Jo Dandy Hill and the Monogram Bench on the south, and Long Park on the north rim, was apparently the site of the most intense prospecting in the 1900-1905 period. Soon prospectors spread out over the entire region from Gateway to Slick Rock as the market for carnotite developed.

Well financed companies such as Standard Chemical, RLM and Radium Company of Colorado brought with them power drilling capabilities not generally available to the independent prospector. Subsurface exploration behind rim exposures or mine workings was done with jackhammers, powered by compressed air from a gasoline powered compressor, or by gasoline-driven core drills. Jackhammers drilled dry and could be used to a depth of 30 feet. Drillers looked for color changes in the dust as an indication of ore. Diamond core drills and those using steel shot could drill to depths up to 60 feet but needed water to cool the bits. Water was generally scarce and had to be hauled to the drills on burros. Freighters charged miners $1.25 a barrel to haul water from Paradox Valley to mines and camps on the Monogram Bench (Dare, 1959). Such requirements restricted drilling in rugged terrain far from water supplies. The initial mining for radium was done with rim cuts on mineralized outcrops or by driving adits into a mineralized

mineralized outcrops. When an orebody was located by exploration drilling behind a rim exposure or mine workings, a decline was driven to the orebody from the mesa top or bench on the mesa. Declines were generally at a maximum grade of 13 percent. For many years prospectors and miners believed in the "rimrock" theory of ore deposition where orebodies only occurred on canyon rims or just behind them. Because of this idea, exploration was limited to canyon rims.

Hardrock mining methods were used in the underground mines employing rails and small ore cars. Loaded ore cars were moved to the surface by man or animal power, or pulled up a decline by a gasoline powered winch. Sublevel haulage was used so that ore could be shoveled from the ore zone into a car on a lower level. A type of open room and random pillar mining method was used. Local timber was used to support the back (ceiling) in large stopes (rooms). Holes for blasting were drilled with a jackhammer run by compressed air and cooled with water. Some miners drilled dry when water was scarce. Every mine had a gasoline powered air compressor and a water tank. Gasoline-powered fans were used to blow out the powder smoke after blasting and to supply fresh air to the miners in the large mines. Miners used carbide lamps underground. After the ore was moved to the surface at the mine site it was sorted visually, by hand, into shipping ore and milling ore. Shipping ore was to contain a minimum of 2.00 percent U_3O_8 where milling ore contained less than 2.00 percent U_3O_8. Miners judged the grade of the ore by the amount of visual yellow carnotite. Coffin (1921)

noted that in an average ore deposit for every five tons mined, there was one ton of shipping ore and four tons of milling ore. With the exception of companies with concentrators, milling ore was hand stacked at the mines. During the winter months, ore was sorted in heated sheds at the mine site.

Shipping ore was packed into 75 pound canvas bags at the mines and loaded onto burros for the trip off the mesas. Some burro trains took milling ore directly to the concentrators. At the nearest road, in the valleys, the bags were loaded onto freight wagons for shipment to the railhead at either Whitewater or Placerville. The six-horse teams, pulling two wagons in tandem, could haul five to five and one-half tons of ore. In good weather it took an average of four days to make the 63 mile trip from Long Park to Placerville.

Due to the remoteness of the mining areas, camps were established in the areas of the larger mines. Coffin's (1921) excellent map of the carnotite region, prepared in 1914-1918, shows camps on Tenderfoot, Calamity, Outlaw, and Flat Top Mesas in Mesa County, Club Mesa, Eagle Basin, Hieroglyphic Canyon, Long Park, Saucer Basin and on the Dolores and Monogram Benches in Montrose, County, and at Slick Rock and the Horse Range Mesa in San Miguel County. The availability of water was a factor in selecting a camp site.

Operating costs were high because of the isolation of the mines; for example, Placerville, Colorado, about 65 miles from the Joe Junior camp, was the nearest shipping point. Concentrates,

ores, and supplies were hauled by freight wagon between Placerville and Joe Junior and to other points within the area. The freight rates between Joe Junior and Placerville were $27.00 per ton in 1914, but by 1922, rates had been reduced to $14.00 per ton as a result of road improvements and the introduction of motor trucks (Bruyn, 1955).

Because of the high freight rates, the Radium Company of Colorado and the Radium Luminous Material Corp. found it unprofitable to mine and ship ore assaying less than 2.00 percent U_3O_8. The Standard Chemical Company could mine and mill ore running as low as 1.25 percent U_3O_8, although the average grade of ore treated in this plant was over 1.50 percent U_3O_8. In 1918, at the height of the radium boom in southwestern Colorado, Hess (1921) counted the following number of men at the mines in the Paradox Valley area; Standard Chemical, 200; Radium Luminous Material 45; Radium Company of Colorado 35; ad George Pickett 25 men. Pickett was an independent miner who sold ore to Standard Chemical.

In 1919, ores containing 2 percent U_3O_8 and 3 percent V_2O_5 were worth between $130 to $140 per ton at Placerville or Whitewater (Coffin, 1921). In that same year, Coffin (1921) estimated the annual ore production from the region was 9,300 tons which averaged 2.00 percent U_3O_8 and 4.00 to 4.50 percent V_2O_5.

The processes used to produce radium salts from carnotite ore were rather crude compared to today's technology. The most commonly used process was the "direct-dissolution process". Carnotite ore, after crushing, was placed in acid-proof brick tanks, and treated with hydrochloric acid to dissolve the carno-

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tite. The solution was then treated with sulphuric acid and barium chloride to precipitate barium as sulphate. Radium precipitated with barium as radium-barium sulphate (radiobarite). The resulting liquor which contained uranium and vanadium in solution and radium-barium sulphate in suspension was decanted through an opening in the side of the tank level at the top of the quartz sand tailings. In order to maintain the sulfates in solution the sand-liquor mixture had to be stirred. Radium-barium sulphate has a specific gravity of 4.5 so that it would settle in the tank rapidly if the mixture was not stirred. The radium-barium sulphate in the decanted solution was allowed to settle and the uranium-vanadium solution was removed. Most plants recovered the vanadium, but the uranium was usually discarded into the sewers. The bed of tailings remaining in the tank was washed with water, stirred, and decanted again. The ore tailings were then conveyed to a dump. The separated radium-barium sulphate was then treated through a series of chemical procedures, involving sodium carbonate and hydrochloric acid, to produce the final product, radium chloride (Landa, 1987).

A second process known as the "indirect-dissolution process", leached the ground ore with a sodium bicarbonate solution to dissolve the uranium, which was removed in solution. The remaining solids were then boiled with hydrochloric acid before the sulphuric acid and barium chloride were added. The remaining part of the process was the same of the direct process. (Landa, 1987).

The beginning of World War I in 1914 had little effect on the mining of carnotite ores though it did affect the European market. Because of the increasing demands for vanadium, radium plants were engineered to recover quantities of vanadium as a byproduct from carnotite. With the entry of the United States into the war in 1917, emphasis slowly began to shift away from the production of radium to the production of vanadium. By 1922 Colorado Plateau ores were no longer competitive with newly developed high-grade pitchblended ores in the Belgian Congo (now Zaire) as a source of radium.

The end of the war caused both a drop in the demand for vanadium and a resumption of production from lower cost areas such as Rifle and Placerville. Mining and milling of carnotite ores ceased around 1923 and was not resumed in most districts of southwestern Colorado 1936.

From 1910 to 1923, about 67,000 tons of carnotite ore were mined in southwestern Colorado and southeastern Utah (Fischer, 1968, p. 738). Approximately 202 grams of radium, 1,068,000 pounds of vanadium oxide, and a small amount of uranium oxide were produced. Fischer (personal communication, 1989) has estimated that approximately 185-190 grams of radium came from southwestern Colorado ores. Table 1 lists the areas in southwestern Colorado where radium ore was mined.

Table 1. Areas of Radium Production, Southwestn Colorado

Area	Estimated Amount Of Ore Produced
Mesa County	
Beaver Mesa	Small
Blue Creek	Moderate
Calamity Mesa	Small
North Fork Mesa Creek	Small
Outlaw Mesa	Small
Tenderfoot Mesa	Small
Montrose County	
Bull Canyon	Moderate
Carpenter Flat	Small
Club Mesa	Very Large
Dolores Bench	Large
La Sal Creek	Moderate
Little Gypsum Valley	Small
Long Park	Very Large
Roc Creek	Moderate
Silveys Pocket	Moderate
Wedding Bell Mt.	Small
Wild Steer Canyon	Small
San Miguel County	
Bush Canyon	Small
Radium Mountain	Small
Slick Rock	Moderate
Summit Canyon	Small

Compiled from Coffin (1921) and Webber (1947).

VANADIUM

Prior to 1930, most of the vanadium produced in the United States came from roscoelite deposits near Rifle and Placerville, Colorado. In 1928, U.S. Vanadium Corporation (USV), a subsidiary of Union Carbide and Carbon Corporation, anticipated a growing market for vanadium, and purchased from Standard Chemical the Joe Junior concentrator and 3,500 acres of mining claims in southwestern Colorado. About 1930, Rare Metals Company built a vanadium plant west of Naturita, Colorado, but it did not operate. In 1931 Shattuck Chemical Company built a vanadium and radium extraction plant near Slick Rock, Colorado. Between 1934 and 1935, the assets of the Colorado Radium Company and the U.S. Radium Corp. were acquired by the Vanadium Corporation of America (VCA) (Webber, 1947).

After a period of comparative inactivity, the rising demand for vanadium by the alloy-steel industry renewed interest in the deposits. Between 1924 and 1935 about 8,000 tons of carnotite ore were mined in southwestern Colorado and southeastern Utah (Fischer, 1968, p. 738). Most of the established mines were reopened by 1935. USV moved its plant from Rifle to the Joe Junior site in 1935 and altered the metallurgical process to handle carnotite at the rate of 240 tons per day. The next year the townsite of Uravan was founded. Also in 1936, Utah Vanadium Corporation built a small plant (25 tons per day) at Cedar in Disappointment Valley. VCA purchased the Naturita mill from Rare Metals in 1939, rebuilt it and built a townsite at Vancorum. The plant began operating in

1940 at the rate of 100 tons per day. Also in 1939, North Continent Mines, Inc. purchased the Slick Rock plant from Shattuck Chemical. It could process 20 tons per day.

Prospecting continued, and many new mines were developed throughout the area. A small mill (15 tons/day) was built at Gateway, Colorado, by Gateway Alloys, Inc., in 1939. The United States' entry into World War II in 1941 gave the vanadium industry new impetus.

Prospecting for new exposures of vanadium minerals continued using visual observations. The higher grade vanadium ores were known by their bluish-black color rather than a canary yellow color. The darker color was due to the vanadium minerals vanoxite and montrosite. Based on the location of the existing radium mines, prospectors learned to look in the sandstone beds of the Salt Wash Member of the Morrison Formation, especially in the uppermost beds.

Exploration drilling behind mines and outcrops used both percussion and diamond drilling. Drill rigs had become truck mounted and water trucks delivered water to the diamond drill rigs. Cores were scanned visually and samples were taken to the lab to determine the vanadium content. In the case of percussion drilling, black or brown dust indicated vanadium minerals had been encountered. Drilling depths rarely exceeded 60 feet for diamond drilling and at 30 feet for percussion drilling.

Mining methods used in the late 1930's and early 1940's were essentially the same as used in the radium days. Adits from the

canyon rims or declines on mesa tops or benches was the mode of entry. Sublevel tracked haulageways were used with the ore cars moved to the surface by men or animals. Declines used gasoline powered hoists. Gasoline powered air compressors provided air for drilling and gasoline powered motors turned fans for ventilation to remove powder smoke.

Some of the first mining done for vanadium was to ship the "milling ore" which had left stacked at the radium mines. All of the radium mines were reopened for the vanadium ore. With the mills nearby, mines were able to ship material in the grade range of 1.50-2.00 percent V_2O_5.

In order to stimulate the production of strategic materials for World War II, the federal government formed the Metals Reserve Company in 1942. As a hardening agent for steel, vanadium was one of the strategic materials, and Metals Reserve began an ore purchasing program and increased the base price paid for vanadium. Mills at Monticello, Utah, and Durango, Colorado, were built and operated for Metals Reserve by VCA and USV, respectively. To insure a steady supply of ore for the mills, Metals Reserve established buying stations and stockpiled ore for distribution. USV was the purchasing agent for Metals Reserve.

The Metals Reserve program, which lasted from 1942 through February 1944, greatly stimulated prospecting, and many new deposits were found. After the termination of the program, vanadium mining all but ended in the area. With the mines closing, the mills had to reduce operations. Listed below are the vanadium

mills in southwestern Colorado that were operating during the Metals Reserve Program.

Location	Owner	Daily Capacity, Tons
Uravan	U.S. Vanadium Corp.	240
Naturita	Vanadium Corp. Amer.	100
Durango	Metals Reserve Co.	100
Slick Rock	North Continent Mines	20
Gateway 1/	Gateway Alloys, Inc.	15

1/ closed in 1943

Source: Huleatt and other (1946)

At a vanadium mill, sodium chloride was added to the crushed carnotite ore. It was added to equal about 6 percent of the weight of the ore. The resulting mixture was roasted at a temperature of about 1,600°F. The hot calcines were quenched into water and leached in precipitation tanks. A red cake was precipitated from the pregnant water-leach liquor by the addition of sulfuric acid and heat. Enough acid was added to produce a p H of 2.5-3. The filtered red cake was washed and either dried or fused before shipment. The dissolved uranium was discarded into the tailings pond with the sand tails. (Colorado Metal Mining Fund Board, 1961).

In an effort to assist the miners to locate and produce more ore, the U.S. Bureau of Mines conducted a core drilling project behind mines in the region from April 1943 to December 1943. (Huleatt and other, 1946). The Bureau was assisted by the U.S. Geological Survey. During the project, a total of 895 holes were drilled with a footage of 38,510 feet. Drilling was usually done

40-50 feet ahead of mine workings. Areas where mines were drilled include the Cottonwood Wash, Yellow Circle, Thompson and Polar Mesa in Utah and Calamity, Tenderfoot, Outlaw and Club Mesas, Gypsum Valley and Slick Rock areas in Colorado. The areas that were drilled were controlled by small companies that did not have the resources for exploration as did the larger companies. As the result of the drilling, some 53,000 tons of ore were discovered. In addition to the Bureau of Mines program the U.S. Bureau of Public Roads and the U.S. Grazing Service built or/and improved roads to the mining areas.

In December 1942, geologists and engineers from the Army's Corps of Engineers, Manhattan Engineer District (MED) made a survey of the operating vanadium mills on the Colorado Plateau to investigate the possibility of recovering the uranium from the tailings at the mills. The carnotite deposits of the Colorado Plateau were the largest known source of uranium in the United States and MED needed it for raw material for the Manhattan Project (first atomic bombs). In southwestern Colorado, contracts were signed with USV, VCA, and Metals Reserve to acquire tailings.

Treatment plants were built in the spring of 1943 at Durango and Uravan to reprocess the tailings. Tailings from mills at Loma, Gateway, Naturita and Slick Rock were trucked to Uravan for treatment. The treatment plants were built by, and operated by USV for MED. The treatment plants produced a green sludge which was further processed at a refinery in Grand Junction to make a form of yellowcake (uranium concentrate). A vanadium concentrate was also

40-50 feet ahead of mine workings. Areas where mines were drilled include the Cottonwood Wash, Yellow Circle, Thompson and Polar Mesa in Utah and Calamity, Tenderfoot, Outlaw and Club Mesas, Gypsum Valley and Slick Rock areas in Colorado. The areas that were drilled were controlled by small companies that did not have the resources for exploration as did the larger companies. As the result of the drilling, some 52,030 tons of ore were discovered. In addition to the Bureau of Mines program the U.S. Bureau of Public Roads and the U.S. Grazing Service built or/and improved roads to the mining areas.

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produced at the Grand Junction refinery which was operated by USV. A uranium circuit was installed at VCA's Naturita mill to produce a yellowcake directly.

All of the facilities operated until late 1945 when they were closed down by MED. Over 3 million tons of tailings were reprocessed. From the Colorado Plateau vanadium operations, MED acquired 2,698,000 pounds U_3O_8, or 14 percent of the total uranium produced for the Manhattan Project (U.S. Department of Energy, 1982).

To evaluate the uranium resources of the Salt Wash Member of the Morrison Formation of the Colorado Plateau, MED contracted with Union Carbide and Carbon Corporation to create a raw-materials appraisal group. This group, known as Union Mines Development Corporation (UMDC), was formed in 1943 and was active through 1946.

UMDC geologists systematically studied the uranium-vanadium deposits of the area. All of the known outcrops of uranium-vanadium minerals, prospects, and mines were mapped and described. Their work was thorough, and few outcropping occurrences of uranium-vanadium minerals known today were overlooked by UMDC. Because Union Mines was a subsidiary of Union Carbide, another subsidiary, U.S. Vanadium Corp., was not permitted to acquire claims or leases on federal lands until early 1970's.

Union Mines research developed a field bead test for uranium detection and a truck mounted machine for measuring and recording radioactivity in a drill hole. Research was also done on the

development of improved portable Geiger-Muller counters for field use.

As part of their investigations, UMDC geologist recommended areas that should be acquired by the federal government for the development of uranium resources. In southwestern Colorado, UMDC acquired two properties: 42 claims of Gateway Alloys on Calamity Mesa, and the holdings of North Continent Mines, Inc. at Slick Rock. The latter included a mill, campsite, 82 claims and miscellaneous mining equipment. The acquisition cost for North Continent Mines was $224,000 and Gateway Alloys was $40,000 (Manhattan District Engineers, 1947).

With the end of the war in 1945, the need for vanadium was declining and most mills were closing. The MED also closed its tailings treatment plants. At that time, UMDC estimated that ore produced in southwestern Colorado was 640,543 tons of ore with an average grade of 1.90% V_2O_5. Details of this production are given in Table 2.

Table 2. Pre-1946 Vanadium Ore Production, Uravan Mineral Belt

District	Tons of Ore	Pounds V_2O_5	% V_2O_5
Beaver Mesa	2,770	110,800	2.00
Bull Canyon	18,660	813,576	2.18
Calamity 1/	26,150	1,004,160	1.92
Carpenter Ridge	3,000	114,000	1.90
Coyote Mesa	700	26,600	1.90
Dolores River 2/	38,500	1,694,000	2.20
Gypsum Valley	20,000	760,000	1.90
Slick Rock	60,200	3,010,000	2.50
San Miguel River 3/	50	1,500	1.50
Uravan			
East Paradox 4/	15,845	579,927	1.83
Club Mesa	163,147	6,297,474	1.93
Long Park	213,477	7,557,068	1.77
Ophir 5/	66,536	1,902,930	1.43
Misc.	8,508	318,199	1.87
West Paradox 6/	3,000	150,000	2.50
TOTAL	640,543	24,340,234	1.90

Source: Union Mines Development Corp (Webber, 1947)

1/ Includes Tenderfoot, Calamity, Outlaw and Flat Top Mesas
2/ Joe Davis Hill area, San Miguel Co.
3/ Vancorum area
4/ Monogram Bench
5/ Atkinson Mesa
6/ La Sal Creek area

U. S. Vanadium Corp was largest producer of vanadium ore followed by VCA. Other important producers were North Continent Mines, Inc, and Gateway Alloys Corp. F. A. Sitton was an important independent producer in the Slick Rock area.

URANIUM

All of the activities of the Manhattan Engineer District and the numerous government-owned facilities in which many of them were performed, were transferred to the Atomic Energy Commission (AEC) by Executive Order 9816, effective at midnight, December 31, 1946. The creation of the AEC transferred the development of atomic energy from a secret military organization to a civilian agency, whose general activities were a matter of public record.

The procurement aim of the AEC was to purchase uranium in concentrates. Its first uranium procurement action was execution of a contract with Vanadium Corp. of America (VCA) on May 28, 1947, for the delivery of concentrates from its mill at Naturita, Colorado. This was followed by contracts on October 2, 1947 and April 13, 1948 with United States Vanadium Corp. (USV) for delivery of concentrates from its mills in Rifle and Uravan, Colorado (Albrethsen an McGinley, 1982).

The AEC opened an ore-buying station at Monticello, Utah in April 1948. This would provide a market for independent miners in the region. In the southern part of the region, VCA acquired the

Durango mill and signed a contract to produce uranium concentrate for the AEC, effective October 8, 1948. Climax Uranium Company signed a contract with the AEC on July 10, 1950 to produce uranium concentrates from a new mill to be built in Grand Junction, Colorado. This was the first mill to be built in the United States solely for the production of uranium with vanadium as a byproduct (Albrethsen and McGinley, 1982).

The production of uranium concentrates was directly dependent upon an assured supply of uranium ores, which required a rapid expansion of exploration and mining efforts. At the beginning of 1947, the known uranium ore reserves were estimated by Union Mines Development Corporation at about one million tons with an average grade of 0.20 percent U_3O_8, This was not sufficient to meet the national defense requirements. the AEC announced a domestic procurement program designed to stimulate prospecting and to build a domestic uranium mining industry in April 1948. Private industry would be tasked with finding, mining, and processing uranium ores. The AEC could assist by making geologic surveys, furnishing free testing and assaying services, and, most important, guaranteeing the market.

The AEC ore market guarantee was promulgated by a series of Domestic Uranium Program Circulars, several of which were occasionally revised and extended. On April 11, 1948, the agency issued its initial ore purchase schedule and bonus incentives in the form of Domestic Uranium Program Circulars 1, 2 and 3. Circular 1 guaranteed a minimum price for certain high-grade uranium ores for

10 years. Circular 2 offered a $10,000 Bonus for the discovery and production of high-grade uranium ores from new deposits. This bonus was collected only once before Circular 2 expired on April 11, 1958. Circular 3 provided for minimum prices and specifications and conditions under which the AEC would purchase carnotite and roscoelite - type ores at Monticello, Utah. It also established payment of $0.31 a pound for the vanadium content (V_2O_5) of the ores. Ores containing more than 6 percent $CaCO_3$ (high lime) were not acceptable.

On June 1, 1948, the AEC issued Circular 4. It was a revision of Circular 3 and added an additional $0.50 per pound premium for ores assaying 0.20 percent U_3O_8 or more, and set forth a haulage allowance of $0.06 per ton mile, up to 100 miles.

On February 1, 1949, the AEC issued Circular 5. It consolidated Circulars 3 and 4 and increased the price for U_3O_8 in ore, and established premium prices for higher grade ore. In order to provide a market for high-lime uranium-vanadium ores of the Colorado Plateau, the AEC announced on July 10, 1949, that it would purchase such ores at Monticello, Utah under special arrangements to be negotiated with individual producers.

Circular 5 was revised and broadened on March 1, 1951. Circular 5, Revised, stayed in effect until April 1, 1962. More important was the fact that the prices set forth in Circular 5, Revised, became the base of the industry's economics while it was in effect. This schedule contained a base price of $3.50 per pound U_3O_8 for ores containing 0.20 percent U_3O_8 received a base price

grading down to \$1.50 per pound U_3O_8 for ores containing the minimum acceptable grade of 0.10 percent U_3O_8, and ores containing 0.21 percent U_3O_8 and better received a \$0.75 per pound grade premium. Vanadium-bearing ores received \$0.31 per pound vanadium oxide (V_2O_5) for their vanadium content. Circular 5, Revised, also paid a \$0.06 per ton-mile haulage allowance for the first 100 miles.

Circular 6, issued June 29, 1951, established an initial production bonus for new discoveries. This bonus could amount to \$35,000 on the first 10,000 pounds U_3O_8 produced from a new property. This Circular expired March 31, 1960.

The AEC's price schedules, bonuses, allowances, etc created prospecting effort which has never been duplicated in mining history. By the early 1950's portable geiger counters were available to the general public which made detecting radioactivity easy. Larger detectors using sodium oxide crystals called scintillation counters could be mounted in vehicles and small aircraft. Prospectors roamed the hills looking for signs of radioactivity.

Due to its connection with Union Mines Development Corporation, USV could not stake claims, and the other vanadium company, VCA didn't greatly expand its holdings from the earlier vanadium mining. Claims were staked by large mining companies, newly formed uranium companies and numerous individuals. Nearly all of the exposures of the Morrison Formation in southwestern Colorado were covered with claims, including the existing patented and unpatented

claims of the earlier vanadium mines. Private and State lands were leased as the uranium boom began in southwestern Colorado.

In order to develop uranium resources, the AEC contracted with the U.S. Geological Survey (USGS) to explore and study the region. The AEC withdrew land from mineral entry so that the USGS could drill for uranium. Between 1947 and 1956, the USGS drilled 2,970,000 feet of hole mainly in the Uravan Mineral Belt. The AEC also drilled a significant number of feet in the region between 1946 and 1956. A total of 700 square miles were withdrawn for drilling on the Colorado Plateau. When orebodies were discovered the land was retained by the AEC. The USGS also mapped the geology and described the mines and uranium-vanadium ore occurrences in 18, 7 1/2 minute quadrangles in southwestern Colorado.

The government drilling was successful and large amounts of ore were found. Lands containing ore were leased by the AEC for mining. This first period of mining began in 1949 and lasted until early 1962. Sixty five mines on 50 leases produced 1,070,000 tons of ore valued at about $1,070,000 (U.S. Atomic Energy Commission, 1972).

The government drilling provided an incentive for claim owners to explore their holdings. Diamond core drilling was used with cores taken only in the Salt Wash unit. Cores were scanned with a geiger counter and the mineralized sections sent to the laboratory for assaying. Available water was always a problem for drillers.

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to switch from expensive core drilling to less expensive non-core drilling in the mid 1950's. Non-core drilling used seismograph type of drilling rigs using compressed air to blow the cuttings out of the hole when the rocks were dry and water when wet rocks were encountered. Core drills were still used to obtain samples for mineralogic and disequilibrum studies. Drilling depths increased from less than 200 feet in the early 1950's to over 700 feet in the mid 1950's, as exploration proceeded to the mesa tops that were capped by the Dakota Sandstone. Exploration drilling was generally done on 1,000-foot centers, with the spacing closed down to 200 feet when mineralization was discovered.

Miners in the early 1950's continued to use the same mining method - "open room with random pillars" with a track haulage - that was used in the 1940's. The new mines that were developed in the early 1950's generally were declines on benches behind canyon rims. Most declines had down-grades of between 10 and 25 degrees. Local timber was used for cribbing at the early declines. This material was replaced with purchased lumber at the later mines.

Orebodies that were located at depths greater than 400 feet were developed using vertical shafts. Since shaft sinking cost nearly twice as much per foot as driving a decline, and took specialized men and equipment, only the larger companies sank shafts when necessary. Also, the surface plant facilities at a vertical shaft were more expensive than at a decline.

As the mine workings extended farther back from the portal, compressed air and battery powered locomotives were used to move

the ore cars in mines with track haulage. Diesel-powered "Scoot-creets" and "Youngbuggies" were introduced in the mid-1950's in small mines without tracks. Diesel fuel replaced gasoline to power air compressors, etc.

Wheelbarrows and shovels were the common mucking equipment in the smaller mines. In the larger mines, ore was removed from stopes by air-powered slushers. The slushers scraped the ore with a bucket into ore chutes where cars could be loaded for movement to the surface loadout facility. Overhead-mechanical loaders, powered by compressed air, were used to load mine cars in track drifts. Radiation detection instruments, designed for use underground, permitted the checking of ore faces and muck piles to determine their approximate grade.

Thin ore, less than 3 feet thick, was "split shot" in order to prevent too much dilution. The waste was drilled, blasted, and mucked out first. Then the ore was drilled, blasted, and mucked out. This time consuming and costly practice was necessary to keep the grade of the ore from being diluted to an uneconomic level. Blasting was done with sticks of powder to which was attached a blasting cap and fuse. Early miners had to light the fuses by hand and then retreat from the face. This practice was replaced with electric blasting caps when electricity was available to the mines.

The larger mines installed their own diesel powered electric generators to provide electricity for mine shops and camps, motors for ventilation fans, and battery chargers for electric mine lamps and locomotives. Electricity was also used for motors on hoists at

both declines and shafts. In 1956, San Miguel Power Association, Inc. began the construction of power lines to the mines in the Dare (R) Paradox Valley area (Dave, 1959). Power lines then spread to all of the larger mines in the region. By the late 1960's REA power had replaced the diesel generators at the larger mines and camps.

U. S. Vanadium Corp. changed its name to Union Carbide Nuclear Company in 1956. The extensive holdings, which had been acquired from Standard Chemical, were worked by contract miners exclusively. The other large company in the region, VCA, used company miners as well as leasers to operate its mines. Climax Uranium Co. used both company personnel and contract miners.

Track haulage in the wet mines required constant maintenance. In 1958, Union Carbide began operating a few mines with their own personnel and began testing various kinds of trackless equipment and mine methods. Trackless equipment had the advantage that roadways could follow orebodies much better than track could. By 1960, all of the new declines were trackless using diesel-powered, rubber tired equipment. In 1971 the large, deep, Deremo mine was converted from track to trackless equipment. This mine was serviced by three 750-feet deep vertical shafts.

In 1967, the Eimco 912, a two cubic yard, Load, Haul, Dump (LHD) was introduced to the industry. This piece of equipment could quickly load a diesel-powered tractor-trailer unit or 5-ton Young Buggies. LHD's were in use in all the larger mines until they closed in the late 1980's. The use of large, rubber-tired

equipment underground meant that larger-sized drifts etc. were necessary to accommodate the equipment. In order to drill more efficiently, rubber-tired drill jumbos came into use in the early 1970's.

There was only natural ventilation in the radium, vanadium and early uranium mines. If mines had fans, they were used mainly to blow out the powder smoke after blasting. A common practice was to blast at the end of the day and let the powder smoke dissipate during the evening and night. During the early and mid-1950's there was a growing concern about the hazards of radon gas to the miners, as it was known to cause lung cancer. Federal and State mine inspectors began to suggest more fresh air was need in areas were men were working. In 1958, Union Carbide would shut down work in an area when the radiation exceeded 10 working levels (WL's). By 1962 Union Carbide had adopted a 5 WL shut down. The next year, Colorado Division of Mines adopted a 3 WL shut down. In 1969, the U.S. Department of Labor reduced the exposure to .3 WL's, or no more than 3.6 working level months (WLM's) per year.

To provide the large quantities of air needed to flush out the radon, large mines had vent holes, drilled from the surface, with electric fans installed on the surface. The larger mines had ventilation engineers who saw that fresh air was moving throughout the mines.

Due to the isolated location of many of the mines, camps for the workers were established nearby. Camps consisted of log and rock cabins, wooden shacks, sometimes covered with tar paper etc.

The early 1950's saw the appearance of trailer houses (mobile homes) at the camps. At some of the more permanent camps, well built, frame houses were constructed. Pre-fabricated, steel "Butler Buildings" began appearing at the mines in the mid 1950's for use as shops, office, and warehouses.

Beginning in 1947, when VCA began reopening its mines, ore production in the Uravan Mineral Belt gradually increased ever year (Figure 2). The AEC had guaranteed a market to 1962, under Circular 5 Revised. On May 24, 1956, the AEC announced the establishment of a new domestic uranium procurement program for the period April 1, 1962 through December 31, 1966. The new program guaranteed a Government market for 500 tons of U_3O_8 in concentrate, per year from any one mining property or operation at a flat price of $8 per pound. Thus, in 1956, the stage was set for a continuing AEC concentrate procurement program after March 31, 1962, with an established price for concentrates rather than for ores. The prices, premiums, and allowance paid under Circular 5, Revised, would no longer be in effect. After March 31, 1962, the AEC required that the mill operator pay "reasonable" prices to independent producers.

By late 1957, dramatic increases in reported ore reserves, especially in New Mexico and Wyoming prompted an AEC announcement that "it no longer is in the interest of the Government to expand production of uranium concentrate." Then, on November 24, 1958, in order to prevent further expansion of production under its essentially unlimited purchase commitment, the AEC redefined its

1962-1966 procurement program by withdrawing portions of the program announced in May 1956. The Government stated it would buy, in the 1962-1966 period, only "appropriate quantities of concentrate derived from ore reserves developed prior to November 24, 1958, in reliance upon the May 24, 1956, announcement." Other aspects of the program announced in 1956 were retained: the AEC would buy only concentrates; the U_3O_8 price would remain at $8 per pound; and ores would not be purchased nor ore prices guaranteed. Independent producers had to negotiate ore purchase contracts with milling companies in order to sell their ores.

The November 24, 1958 announcement brought to a halt all exploration drilling in the region. The only drilling that continued was development drilling for mine development purposes. Most small independent mining companies and individual were hit hard by the announcement since they did not block out large ore reserves prior to mining. In 1961, the AEC modified the November 24, 1958 regulations and allowed small miners to have their 1962-1966 allocations based on historical production during the July 1, 1956 to June 30, 1960 period.

Ore production in the Uravan Mineral Belt reached an all-time record high in 1960 when 815,645 tons of ore averaging 0.26 percent U_3O_8 and containing 4,231,824 pounds of U_3O_8 were shipped (Figure 2). Of the contained uranium oxide, Union Carbide produced 58 percent, Climax produced 8 percent and VCA less than 1 percent. Following this record high, annual ore production began to decline as AEC allocations (market quotas) went in to effect in 1962.

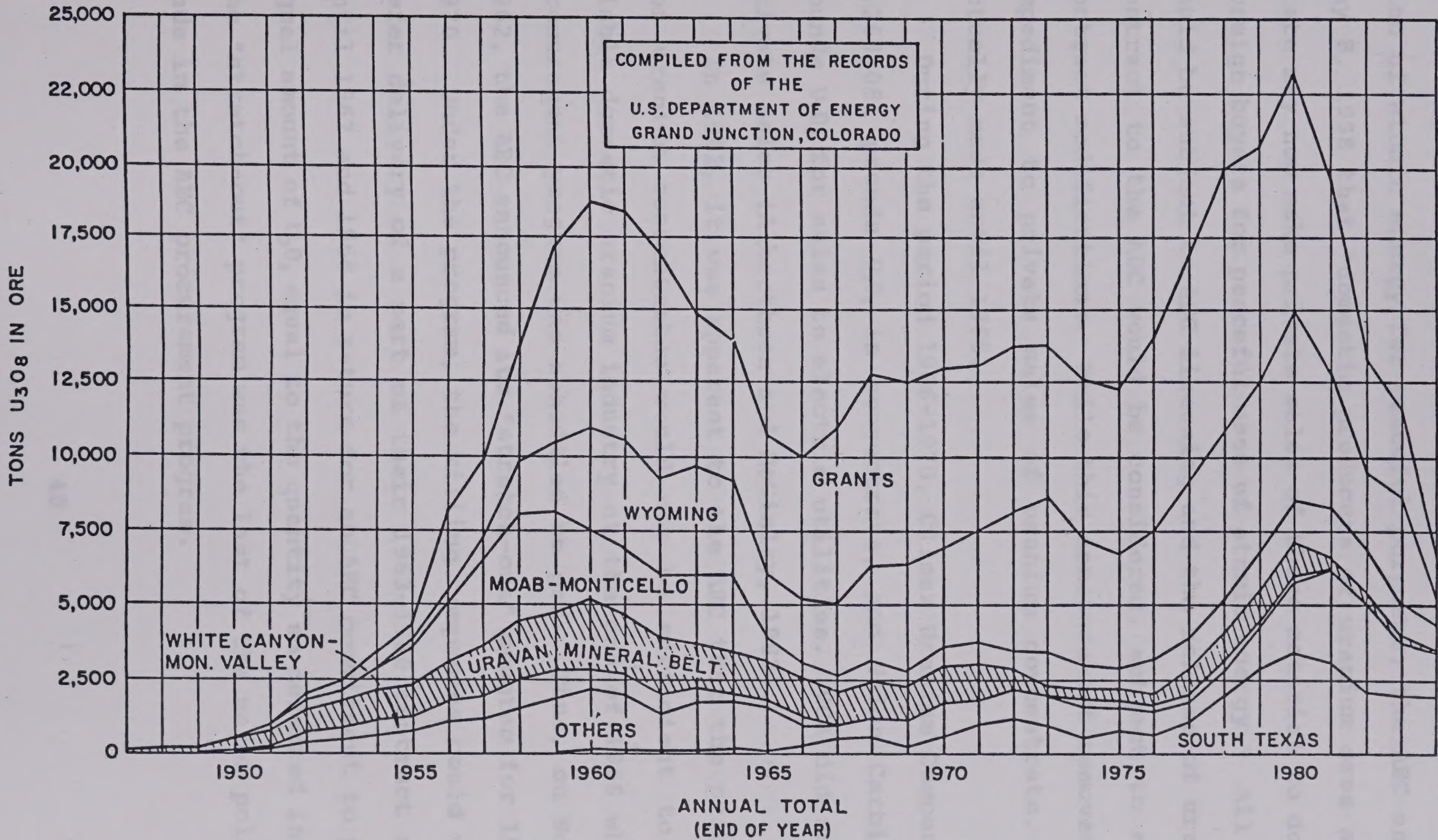

Figure 2. Uranium ore production by area, 1947 through 1984 "Others" indicates all other uranium deposits not included in the indicated groups.

With the objective of fostering the development and utilization of atomic energy for peaceful purposes, the AEC announced on May 8, 1958 that "domestic producers of uranium ores and concentrate may now make private sales of these material to domestic and foreign buyers for peaceful uses of atomic energy." All such sales would be subject to AEC licensing and the release of uranium under contract to the AEC would be considered, subject to appropriate contract modifications. While this announcement removed the legal impediment to private sales of uranium concentrate, note were actually made until 1966.

During the period 1966-1970, Climax Uranium Company produced 2,268,081 pounds U_3O_8 in concentrate, and Union Carbide 728,919 pounds U_3O_8 for sales to electric utilities. VCA did not make any private sales (Albrethsen and McGinley, 1982).

In 1962, it was apparent to the AEC that the private market for uranium concentrates would not be sufficient to sustain a viable domestic uranium industry at the end of 1966 when the AEC procurement program was scheduled to end. Thus, on November 20, 1962, the AEC announced its "stretch-out" program for 1967 through 1970. Under the program, the milling companies could voluntarily defer delivery of a part of their 1963-1966 contract commitments until 1967 and 1968 in return for an AEC commitment to purchase an equal amount of U_3O_8 equal to the quantity so deferred in 1969-1970. The "stretch-out" program was the last of the major policy changes made in the AEC procurement program.

The price to be paid for the deferred material in 1967 and 1968 would be $8.00 per pound, the same as the 1962-1966 contracts. The price to be paid in 1969 and 1970 for concentrate produced from properties controlled by the milling company would be calculated with a formula based on costs during the 1963-1968 period, not to exceed $6.70 per pound. The price for all concentrates produced from ores purchased from independent producers would be $6.70 per pound of contained U_3O_8. Climax Uranium did not stretch out its contract and all uranium produced after 1966 was for private sales.

When the AEC procurement program ended at midnight December 31, 1970, a total of 10,640,855 tons of ore averaging 0.26 percent U_3O_8 and 1.40 percent V_2O_5 had been purchased in Mesa, Montrose, and San Miguel Counties (Table 3). Approximately 55 percent of the tons of ore was produced from Union Carbide controlled mines.

Beginning in 1971 all uranium produced in the United States was for the nuclear power industry. Milling companies bid on contracts with electric utilities and prices paid to independent mines was based on contract prices, Vanadium sold to steel industry was also the subject of prices set by the industry. Ore production declined in the mid-1970's as uranium prices on the spot market reached over $40.00 per pound U_3O_8 in concentrates (Figure 2). What was once low-grade rock (less than 0.20 percent U_3O_8) became ore.

Table 3. Uranium ore purchased by the AEC, 1947-1970.

Counties	Tons of Ore	Pounds U_3O_8	$\%U_3O_8$	Pounds V_2O_5	$\%V_2O_5$ 1/
Mesa	1,862,466	10,995,701	0.30	40,125,561	1.15
Montrose	6,257,950	31,623,099	0.25	66,122,660	1.35
San Miguel	2,520,439 2/	12,175,307	0.24	88,333,341	1.75
Total	10,640,855	54,794,107	0.26	194,581,562	1.40

1/ Grade based on the actual tons assayed for V_2O_5.
2/ Includes 23,150 tons of roscolite ore from the Placerville area.

During 1966-1970 an additional 102,000 tons of ore was produced for sales to electric utilities.

Source: Unpublished AEC records, Grand Junction, Colorado.

Union Carbide estimates that from 1948 through 1972, over 50 percent of the ore delivered to the Uravan mill came from small contract miners and independent miners (Perry, 1981). This emphasizes the importance of the small companies and individuals in the mining history of the region.

In 1974 the AEC held lease sales for the 40 square miles of land it still controlled in Colorado, Utah, and New Mexico. Forty three leases were signed. All were in the Uravan Mineral Belt with the exception of three in Utah and one in New Mexico. As of June, 1986 these leases had produced 1.5 million tons of ore, containing 5.9 million pounds U_3O_8 and 30 million pounds V_2O_5 (Dept. of Energy, unpublished records).

The Cotter Corporation, a wholly-owned subsidiary of Commonwealth Edison, was the successful bidder on many of the leases in Montrose County, Colorado. In anticipation of shipping its ore to its mill in Canon City, Colorado, Cotter built a crushing and sampling plant south of Whitewater, Colorado. The plant, with a covered conveyor and walkway that spanned the Gunnison River to a loading site along the Denver and Rio Grande Western Railroad, was completed in 1977. Only a few carloads of ore were shipped to Canon City and the majority of the ore that was trucked to Whitewater in 1980 was eventually trucked back to Uravan for processing.

In December 1979, Cotter began stripping a large (2,500 feet long, 1,500 feet wide, and 350 feet deep) open pit on the Monogram Bench, on the south side of Paradox Valley. After removing 65 million cubic yards of overburden, the operation was shut down in

April 1981 due to falling uranium prices. (Dept. of Energy, unpublished records).

In the mid 1970's, General Electric's Nuclear Division established an ore-buying station on the site of the former VCA mill near Naturita. This station provided a market for the independent miners who did not wish to ship their ore to Union Carbide at Uravan. The small amount of ore that was purchased was eventually sold to Union Carbide.

Late in December, 1977, the Durita Development Corporation, a wholly-owned subsidiary of Ranchers Exploration and Development Corporation began leaching uranium and vanadium from the old VCA Naturita mill tailings that had been moved to a site in the southeast end of Paradox Valley. During two years of the project, 380,000 pounds U_3O_8 and 1,840,000 pounds V_2O_5 were recovered (Pay Dirt, 1984).

With rising uranium prices, Pioneer - Uravan, Inc. announced in December 1977 that Disappointment Valley had been selected for the site of a new uranium-vanadium mill. The mill was never built due to environmental concerns and falling uranium prices.

Production reached an all time annual high, in the post AEC period, in 1980. During this year 696,939 tons of ore averaging 0.16 percent U_3O_8 and 0.97 percent V_2O_5 and containing 2,310,943 pounds U_3O_8 and 13,558,300 pounds V_2O_5 were produced in the three counties. During 1980 the spot market price dropped from \$40.00 to \$27.00 per pound U_3O_8. the price drop was largely due to overproduction and the general non-acceptance of nuclear power as an

energy source. Long term contracts allowed Union Carbide to continue production. In 1983 Union Carbide Corp's mining and milling operations on the Colorado Plateau became Umetco Minerals Corp.

As uranium prices continued to decline so did production. The last production in the three counties was in late 1990. At that time the spot market price was \$9.70 per pound U_3O_8 and still dropping.

Company controlled mines always shipped their ore to the company's mill for processing. For example, Climax's mines in Bull Canyon would bypass Uravan and truck their ore to the Climax mill in Grand Junction. A VCA mine on Calamity Mesa would pass by Uravan to go to Naturita. Independent miners would go to mill where they thought they would get the best assays.

Ore hauling was done with 6 ton capacity dump trucks. Most trucks pulled a small (2 1/2 ton) trailer, called a pup. In the more rugged locations, ore was brought down off the mesas in a small truck and stockpiled for later loading into highway trucks and pups.

The following summary of milling operations in the Uravan Mineral Belt is taken from a report by Albrethson and McGinley (1982). The former North Continent mill at Slick Rock was acquired by Union Carbide from the AEC in November 1957. Union Carbide removed the tailings to Uravan for reprocessing before reclaiming the site. Across the Dolores River from the North Continent site, Union Carbide operated a 430 tons per day concentrator from

September 1957 to December 1961. Ores purchased at the Slick Rock site were credited to the Rifle mill, but concentrated on site. The concentrates from the Slick Rock site were trucked to Rifle for further processing.

VCA's original plant at Naturita used the conventional salt-roast process. It consisted of ore crushing and dry grinding to minus 14-mesh and subsequent roasting with 7 to 8 percent by weight of salt (NaCl). The roasted calcines were percolation leached with water and the leached residues were sluiced to a tailings pond along the San Miguel River. The vanadium was precipitated as a "red cake" from solution by the addition of sulfuric acid and heat. The red cake was filtered, washed, dried, and fused to form fused oxide suitable for manufacture of ferro-vanadium.

During World War II, and subsequently when uranium recovery was also desired, the neutral water-leach was replaced by an alkaline-sodium carbonate leach solution to extract the uranium. The uranium was recovered as a uranium-vanadium sludge for sale to MED. For sale to the AEC uranium was recovered from solution as synthetic carnotite precipitate (sodium uranyl vanadate) by adjusting the pH of the carbonate liquor to around 6.0 with sulfuric acid and boiling to remove the carbon dioxide (CO_2). This precipitated the synthetic carnotite (yellow cake) which was removed by filtration. The yellow cake contained about 20 percent vanadium and other impurities that required removal. This was accomplished by means of a reducing fusion with salt, soda ash and sawdust or fuel oil. This fusion formed a water insoluble black

uranium oxide and water-soluble vanadium and other impurities. The melt was cooled and water-leached to produce the concentrate, black uranium oxide, which was filtered, dried and packaged for sale to the AEC. The Naturita mill used this process throughout its operating life, although in the latter years of operation an acid leach of the sands was added to increase uranium recovery.

The daily capacity of VCA's Naturita mill had increased to 200 tons per day by 1955 and to 325 tons per day in 1956. The mill was shut down in 1958, but VCA continued to purchase ore at the site and operated an upgrader there until March 1963. Upgraded material from Naturita was shipped to Durango for further processing. The mill process used at VCA's Durango mill provided for separate salt roasting of ores and of concentrates from VCA's upgrader plants and for carbonate leaching of the calcines. Ore calcines were quenched and percolation leached while the concentrate calcines were quenched and then treated by counter-current washing on a series of three drum filters. Pregnant solutions from these two circuits were then combined and a sodium uranyl vanadate, or artificial carnotite, product as precipitated by addition of sodium chlorate, acidification and boiling, then neutralizing to pH 7. The bulk of the vanadium remained in the filtrate and was precipitated as red cake. The reducing fusion and water leaching process was then used to remove the vanadium from the uranium concentrates. The uranium was recovered as black oxide (UO_2), and soluble vanadium subsequently was recycled and precipitated as vanadium red cake. the red cake was dried and fused to produce flake fused oxide.

Tailings from the carbonate leaching operations were reclaimed and retreated for additional uranium and vanadium recovery by acid percolation leaching, using a combination of hydrochloric acid solution recovered from the salt-roaster gas scrubbers and additional sulfuric acid. Beginning in the late 1950's the pregnant acid leach liquor was treated by solvent extraction to recover both uranium and vanadium into a final concentrated and purified carbonate liquor suitable for return to the plant precipitation circuit.

The Durango solvent extraction was unique in that it extracted uranium and vanadium simultaneously rather than employing separate extraction circuits, which was the practice at other mills. The Durango mill increased its daily capacity from 175 tons per day in 1949, to 430 tons per day in 1956 to 750 tons per day in 1958. The Durango plant was shut down in March 1963 when VCA purchased the Kerr-McGee Oil Industries, Inc. mill at Shiprock, New Mexico. After Durango closed, all of VCA's Colorado Plateau ore was shipped to Shiprock. VCA was merged into Foote Mineral Co. on August 31, 1967 and the mill closed in May 1968.

The AEC's ore-buying station at Monticello, Utah closed in March 1962. Since the AEC's mill at Monticello had closed in January 1960, the ore at the buying station was sold to other mills in southeastern Utah.

The Climax Uranium Company's 100 ton per day (tpd) mill began operation in Grand Junction, Colorado in 1951 and was the first mill designed and built in the United States primarily for the

production of uranium with vanadium as a byproduct. The 200 acre site selected by Climax was that of a shut down sugar beet processing plant on the north bank of the Colorado River on the south side of the city. The mill produced uranium, and some vanadium, for sale to the AEC through December 1966. Subsequently, until the mill shut down in 1970, all production was for sale in the commercial market.

Climax was the first uranium mill to use acid leach and uranous phosphate precipitation, a new process developed about 1950. It was based on the fact that uranous phosphate will precipitate selectively from acid liquors, giving a much higher grade uranium cake than that obtained in a green sludge formed by neutralization of the acid. Climax incorporated a salt roast and water leach for vanadium recovery, since its millfeed was typical Colorado Plateau carnotite-type ores. Climax also installed a sand-slime separation step to concentrate about 70 percent of the values into the minus 150-mesh fraction comprising 30 to 40 percent of the weight of the ground ore. This decreased, by about two-thirds, the tonnage of ore to be salt roasted for vanadium recovery.

In plant operations the phosphate precipitation process proved unattractive because the uranium precipitate was too high in phosphate and two low in grade, so Climax installed a solvent extraction (SX) process in 1956 after increasing the plant capacity from 330 to 500 tons of ore per day in 1955.

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At the inception of its AEC contract, the Uravan mill was reactivated, using a salt-roast, water leach for vanadium recovery and neutralization and chemical upgrading for the recovery of uranium, attaining a capacity of about 500 tons per day (tpd) in 1950. In 1955 the new "B" plant was constructed on the canyon rim of Club Mesa above Uravan, expanding the mill capacity to 1,000 tpd. The "B" plant used "hot-acid leaching" rather than the salt-roast process used in the old mill. Both uranium and vanadium are taken into solution during the highly oxidizing two-stage acid leaching. The solids (tailings) are washed in an eight-stage countercurrent decantation circuit. The uranium-vanadium solution from the "B" plant flowed by gravity downhill to the old mill where it is clarified and then passed through ion exchange columns for uranium recovery. The resin is eluted with brine and the uranium is precipitated with ammonia to produce concentrate. The vanadium in the ion exchange effluent is recovered by solvent extraction. Various vanadium products from Uravan have included fused vanadium oxide, ferric vanadate, or higher vanadium grade liquors for shipment elsewhere for vanadium recovery.

By 1976 the Uravan mill had a capacity of 1,300 tpd, due to expansion of the acid leaching circuit in the "B" plant. In 1980, the mill was processing 1,900 tons per day. The mill feed came from six company operated mines, 15-17 contractor operated mines and 6-7 independent mines. Milling operations at Uravan closed in November 1984. After Uravan closed, ore from the region was processed at the White Mesa mill of Umetco Minerals Corp. and

Energy Fuels Nuclear, Inc., at Blanding, Utah. The White Mesa mill went on standby in early 1991.

In summary, the uranium-vanadium ore produced in southwestern Colorado and adjacent parts of Utah from 1947 through 1978 has been 13,987,000 tons with an average grade of 0.25 percent U_3O_8 and 1.29 percent V_2O_5 (Dept. of Energy, unpublished records). This amounts to approximately 11 percent of the uranium ore produced in the United States during that period. A reported 20 million pounds of U_3O_8 are present in ore reserves in the region but a large increase in the prices of uranium and vanadium are needed for the mines and mill to reopen.

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